Search for PentaQuark Partners: JLab E04-012

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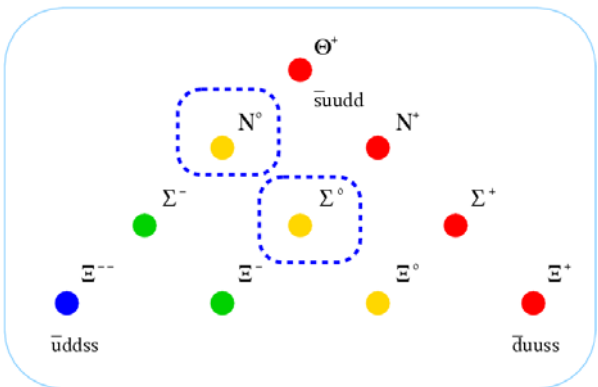
for JLab E04-012 Collaboration

PANIC05 Oct 2005

PentaQuark Model

- Chiral Quark Soliton Model (Diakonov *et al.*, 1997) predicts an anti-decuplet of pentaquarks

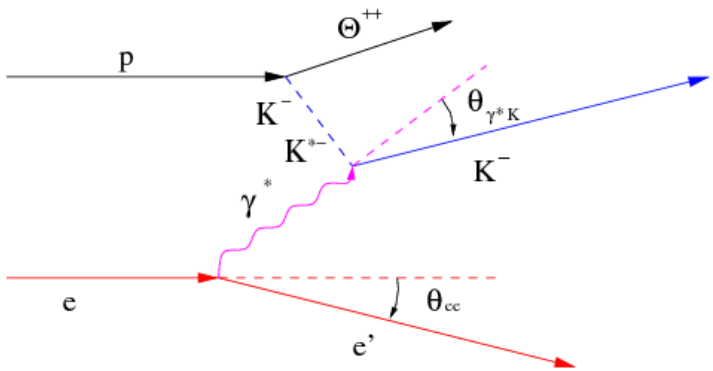


  - **Narrow** (1~8 *MeV*)
  - Low mass (Θ ~1530 *MeV*)
  - $M = M_{\Theta^+} + (1 - S) \cdot 107 MeV$

- One of several alternative explanations of Iso-tensor multiplet (Capstick *et al.*, 2003)

Partners	I_3	Strong Decay modes
Θ °	-1	n K^o
Θ +	0	n K^+, p K^o
Θ ++	1	p K^+

Hall A Experiment E04-012



$H(e,e'K^+)\Sigma^o_{10}$ 1550 – 1810 *MeV*

$H(e,e'K^-)\Theta^{++}$ 1470 – 1600 *MeV*

$H(e,e'\pi^+)N^o$ 1610 – 1890 *MeV*

Beam Energy: 5*MeV*

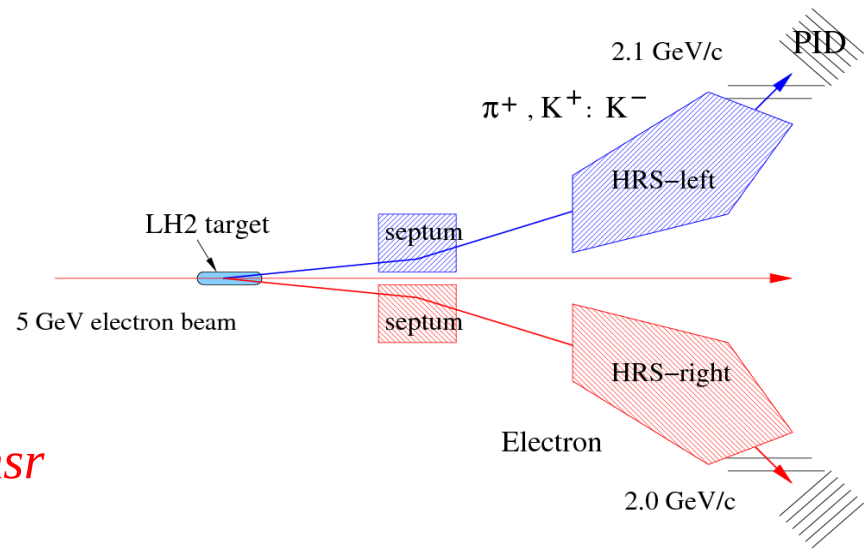
Left and Right HRS angle : 6°

Left HRS Momentum: 2.1 *GeV/c*

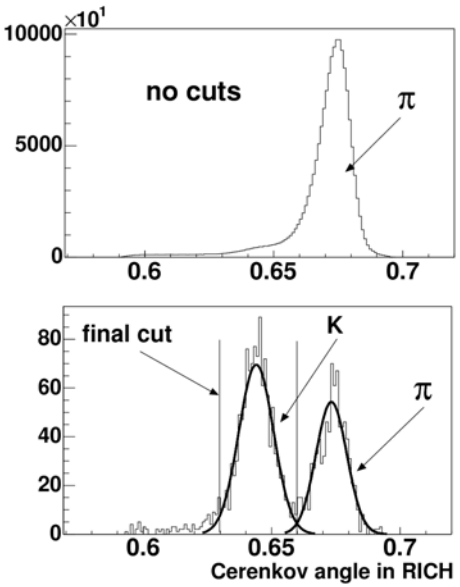
Right HRS Momentum: 2.0 *GeV/c*

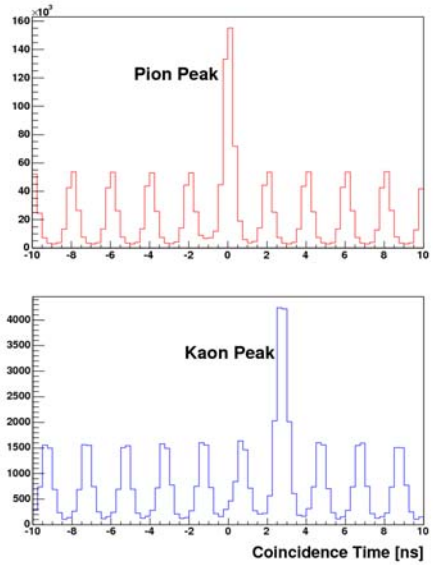
Q^2 : ~ 0.1 $(GeV/c)^2$

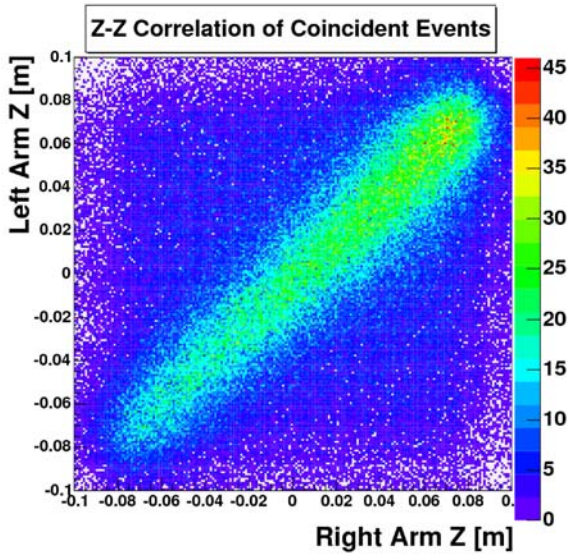
$\theta^{CM}_{\gamma^* K(\pi)}$:~ 7(6)°, $\Delta\Omega^{CM}_{K(\pi)}$:~ 40(30)*msr*



PID and Coincidence System







With A1/A2/RICH

π Rejection ≈ $3 \cdot 10^4$

Final K/ π ratio > 20

TOF Resolution :

FWHM ≈ 600 ps

CT difference ~ **2** ns

Reaction z Resolution:

FWHM ≈ 2.5 cm

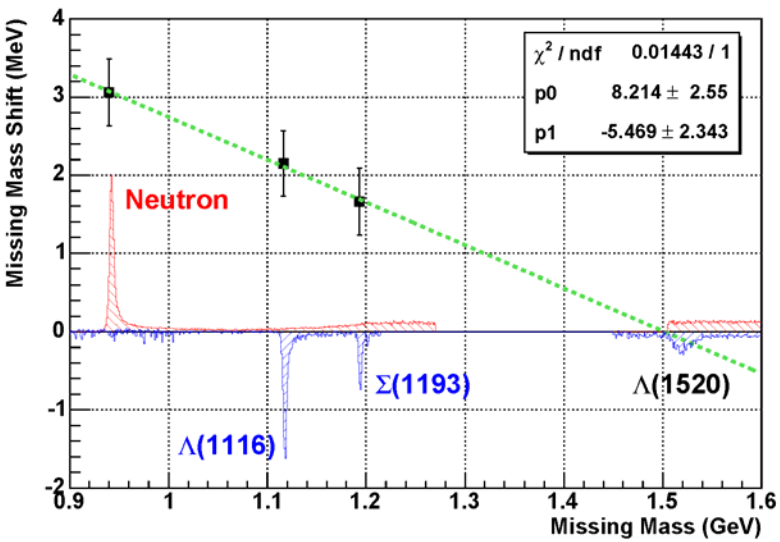
15 cm extended Target removes background by a factor of **2**

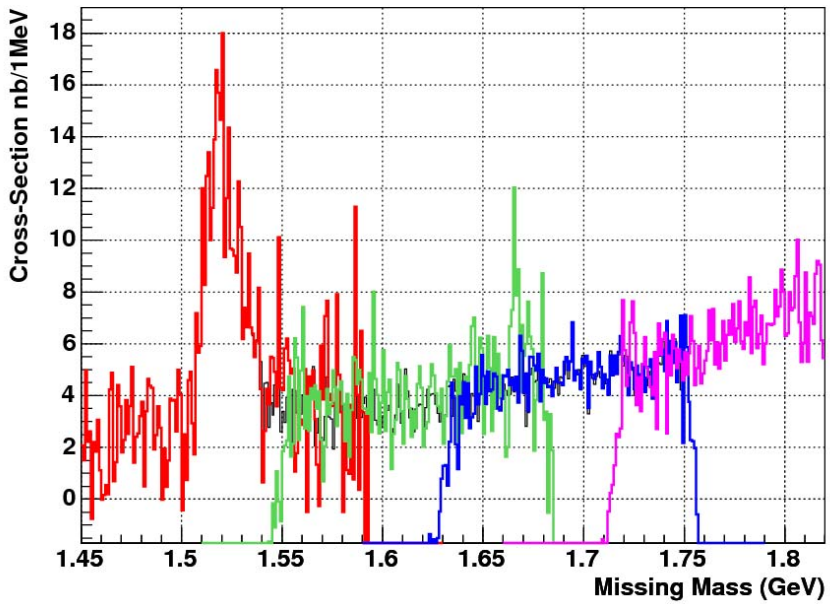
Missing Mass Calibration and Combine Kinematics Settings

High Resolution

$\sigma_{mm} = 1.5\ MeV$

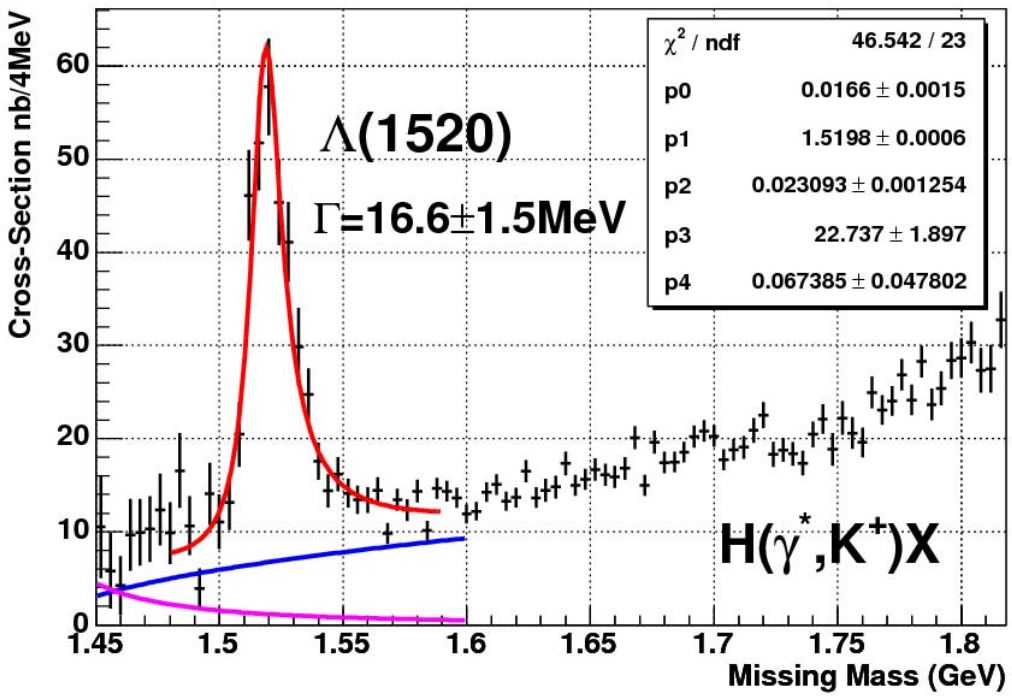
Mass Uncertainty < 3 *MeV*





Due to small acceptance we had **8** kinematics settings combined in total

Parameters of Λ°_{1520}



$M = 1520.2 \pm 0.5\ MeV/c^2$

$\Gamma = 16.6 \pm 1.5\ MeV/c^2$

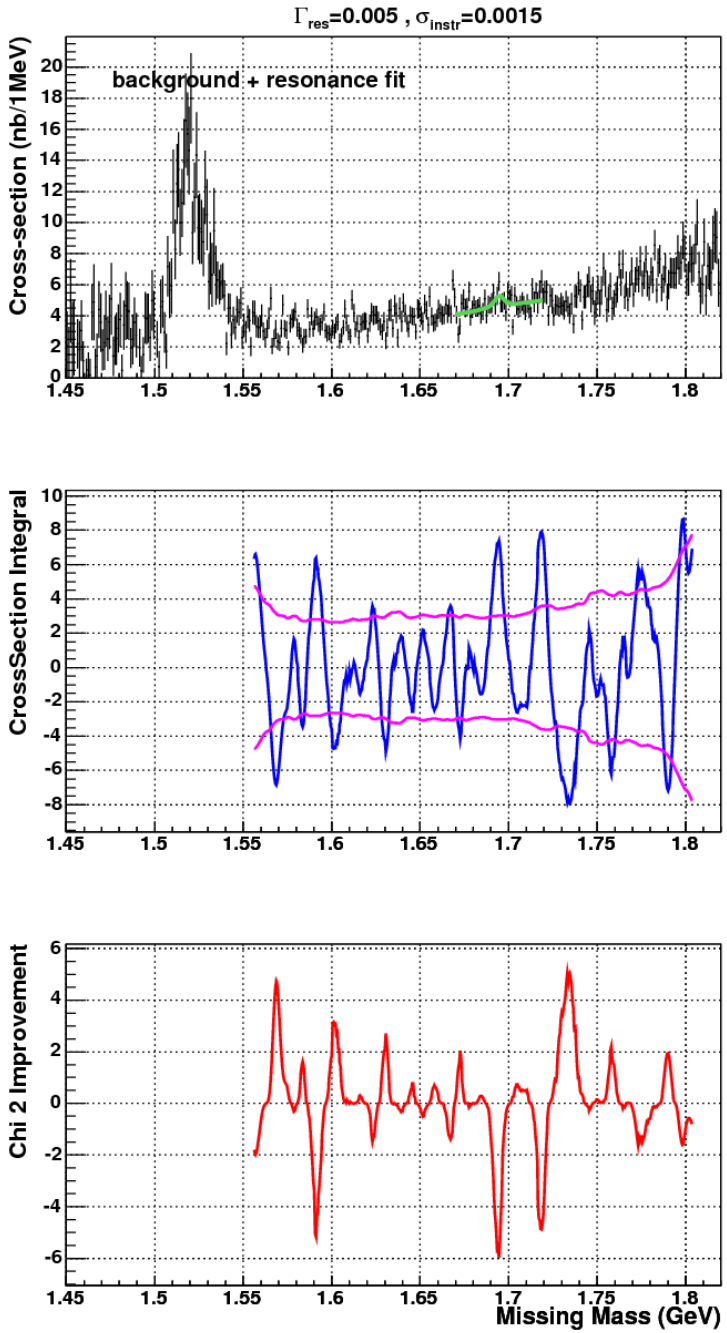
$$\frac{d\sigma}{d\Omega}|_{CM}\ (\gamma^* p \to \Lambda K) \approx 350 nb/sr$$

Σ°_{10} Search

$$p(\gamma^{*},K^{+})\Sigma^{o}_{\overline{10}}$$

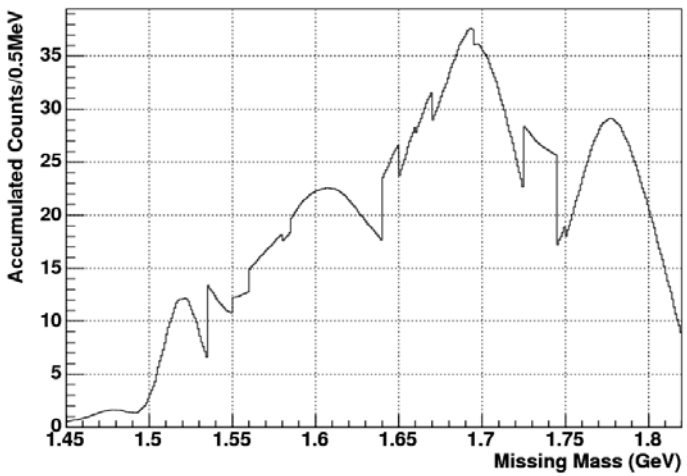
- Background + resonance fit with width 1 ~ 8 MeV
- *Differential* Cross-Section Integral Under resonance: *a*,
- Modified χ^2 Improvement as test statistics:

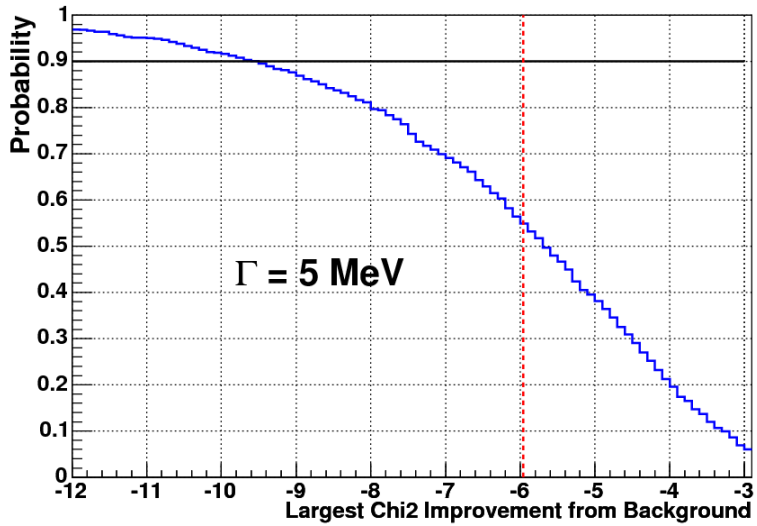
$$\Delta\chi^2 = \begin{cases} \chi^2_{s+b} - \chi^2_b & a \geq 0 \\ -(\chi^2_{s+b} - \chi^2_b)' & a < 0 \end{cases}$$



Background Monte-Carlo

- We simulated 1000 background spectra using real experimental statistics
- Find Largest χ^2 Improvement in each spectrum



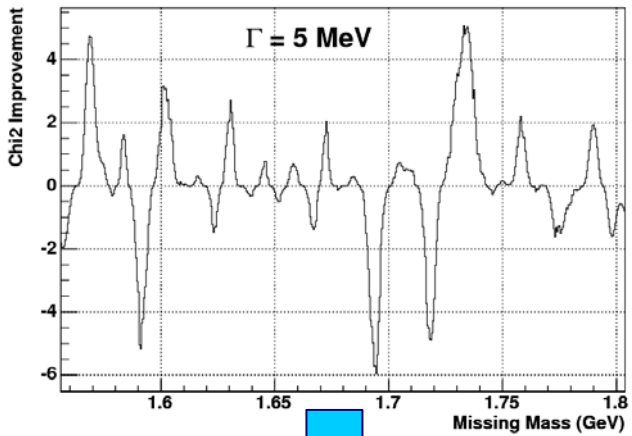


- Distribution of Largest χ^2 Improvement shows the probability of real peak is:

<55%

- Go for upper limits

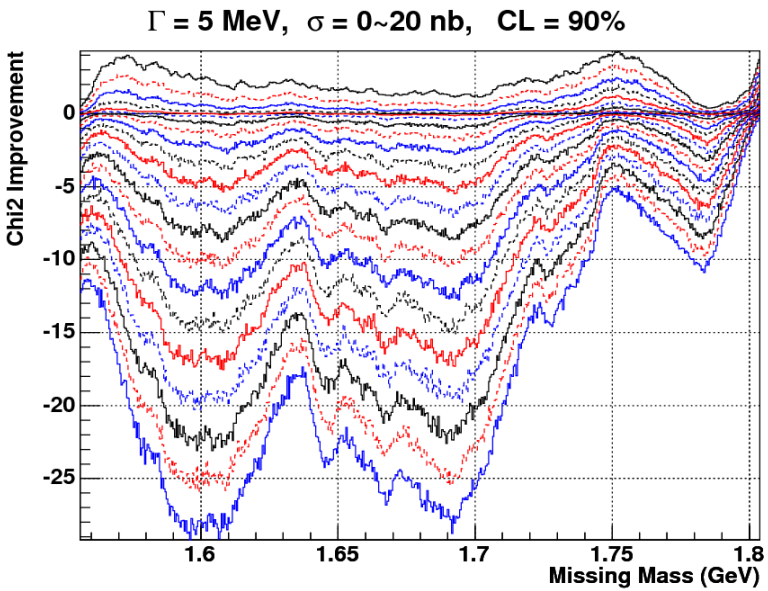
Upper Limit Contour with 90% CL

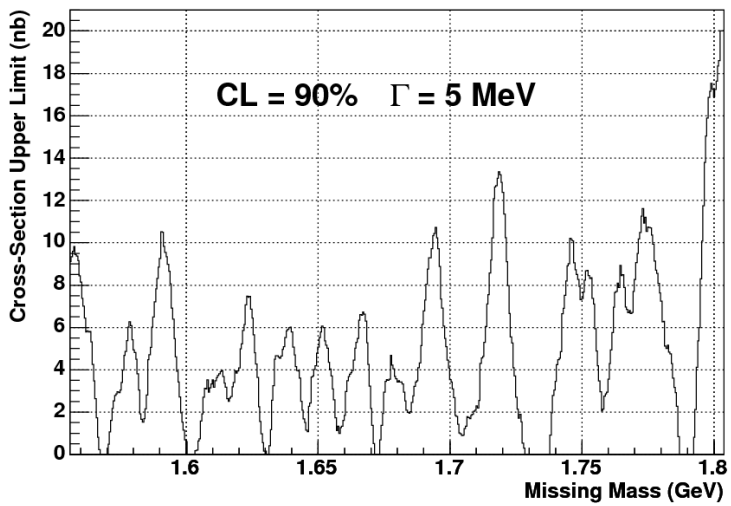


- At M, Insert a peak with certain σ_M
- Find the σ_M giving:

$$P_{\sigma(M)}(\Delta\chi^2 \le \Delta\chi^2_{obs}) = 90\%$$

- Then we have 90% CL to exclude the resonance of σ_M at M





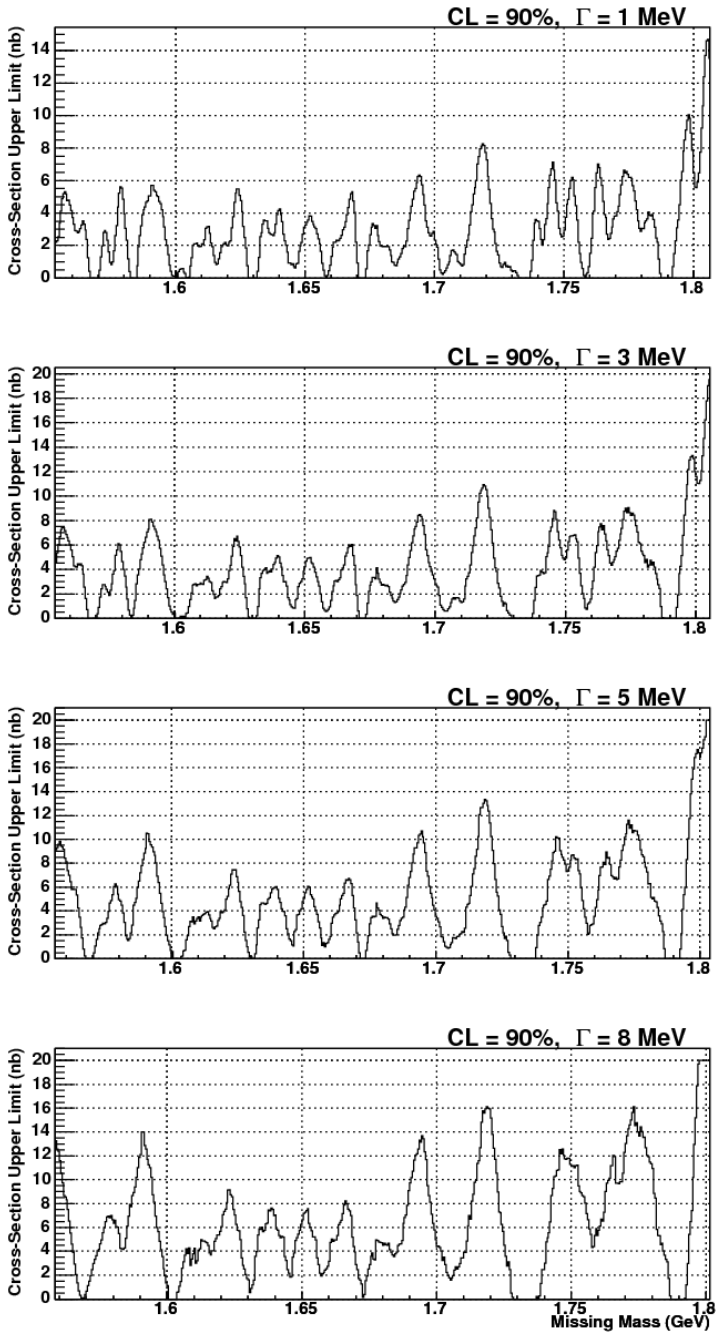
Σ°_{10} Upper Limits

$$p(\gamma^{*}, K^{+})\Sigma^{o}_{10}$$

- Most Significant Peak, 2.3 σ , was found at **1.72** GeV/c^2
- 90% CL upper limit at that position ranges:

8 nb/sr ~ **16** nb/sr

for width : 1~8 MeV



N°_{10} Upper Limits

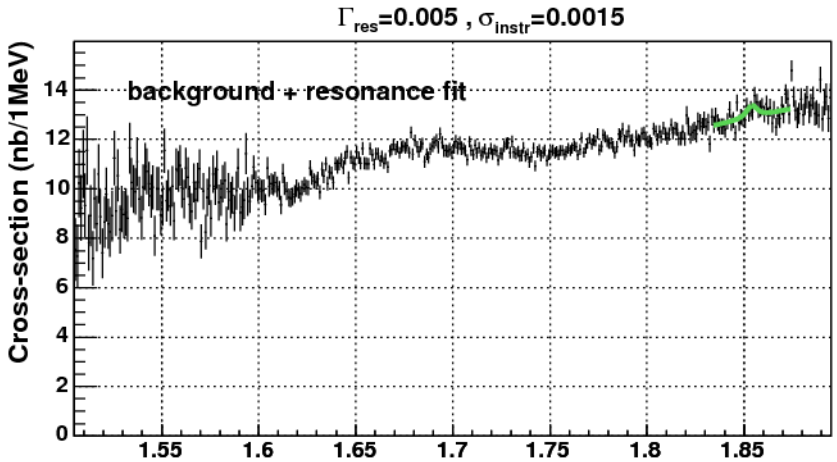
$$p(\gamma^{*},\pi^{+})N^{o}_{10}$$

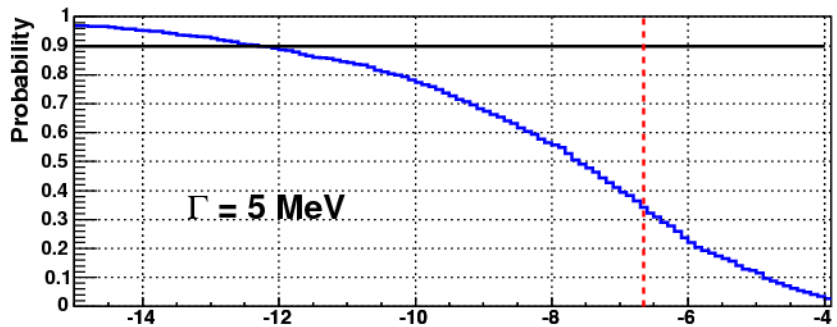
- Most Significant Peaks, < 2.5 σ , are at **1.65**, **1.68**, **1.73** and **1.855** GeV/c^2
- Probability of Real Peak

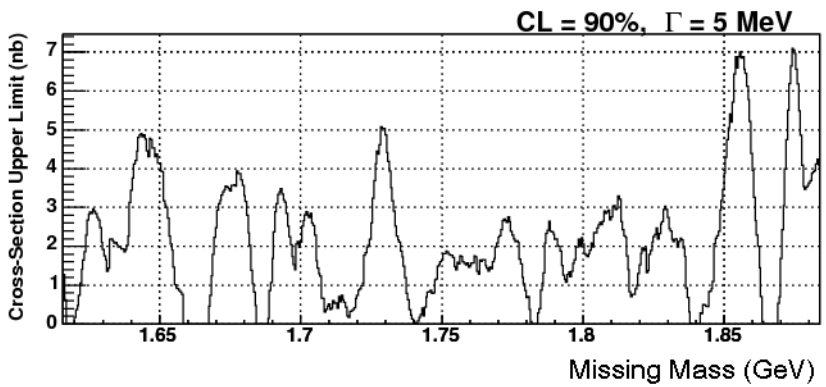
< 50 %

- 90% CL upper limits:

4 nb/sr ~ **9** nb/sr







Θ^{++} Upper Limits

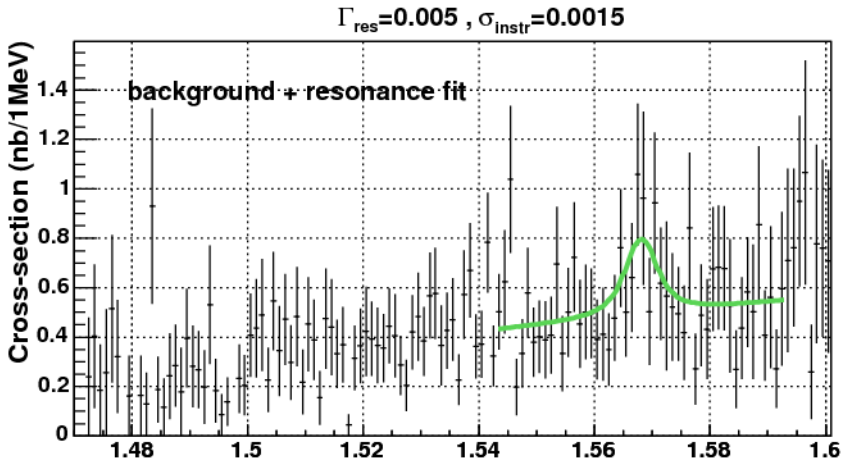
$$p(\gamma^*, K^-)\Theta^{++}$$

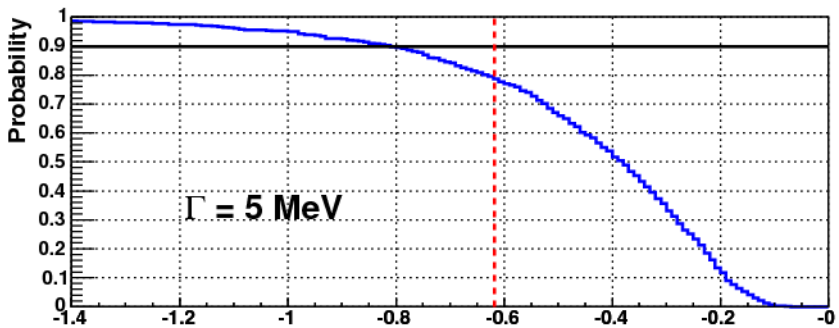
- Change to Log-Likelihood
- Most Significant Peak, 3 σ , is at **1.57** GeV/c^2
- Probability of Real Peak

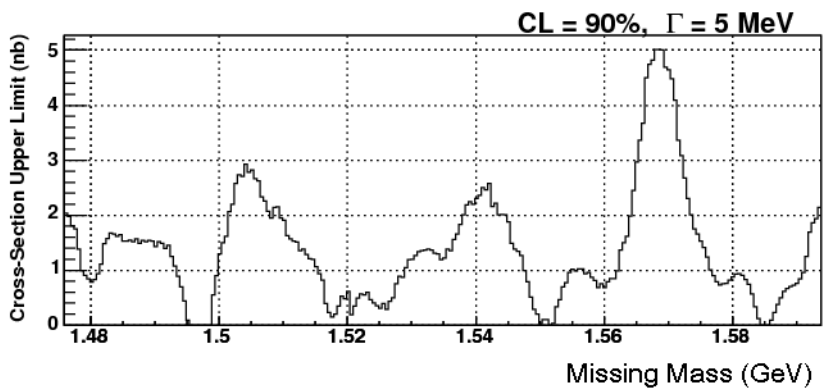
< 80 %

- 90% CL upper limits:

3 nb/sr ~ **6** nb/sr







Summary

- Upper Limit for Σ^0 of 5 *MeV*

$$\frac{d\sigma/d\Omega(\Sigma^\circ)}{d\sigma/d\Omega(\Lambda^*_{1520})} < 3.7\% \qquad \frac{d\sigma}{d\Omega}(\gamma^* p \to \Sigma^\circ K^+) < 13 nb/sr$$

- Upper Limit for Θ^{++} of 5 *MeV*

$$\frac{d\sigma/d\Omega(\Theta^{++})}{d\sigma/d\Omega(\Lambda^*_{1520})} < 1.4\% \qquad \frac{d\sigma}{d\Omega}(\gamma^* p \to \Theta^{++} K^-) < 5 nb/sr$$

- Upper Limit for N^0 of 5 *MeV*

$$\frac{d\sigma/d\Omega(N^\circ)}{d\sigma/d\Omega(\Lambda^*_{1520})} < 2.0\% \qquad \frac{d\sigma}{d\Omega}(\gamma^* p \to N^\circ \pi^+) < 7 nb/sr$$

To be or not to be?

Collaboration

J. Annand, J. Arrington, Y. Azimov, C. M. Camacho, G. Cates,
J. P. Chen, S. Choi, E. Chudakov, F. Cusanno, K. de Jager, M. Epstein,
R. Feuerbach, J. Gomez, O. Gayou (run coordinator), F. Garibaldi,
R. Gilman, D. Hamilton, O. Hansen (analysis coordinator),
D. Higinbotham, T. Holmstrom, M. Iodice, X. Jiang, M. Jones, J. Lerose,
R. Lindgren, N. Liyanage, D. Margaziotis, P. Markowitz,
V. Mamyan (analysis guru), R. Michaels, Z. Mezianni, P. Monaghan,
V. Nelyubin, K. Paschke, E. Piasetzky, P. Reimer (co-spokesperson),
J. Reinhold, B. Reitz, R. Roche, Yi Qiang (Ph.D. student), A. Sarty,
A. Saha, E. Schulte, A. Shahinyan, R. Sheyor, J. Singh, I. Strakovsky,
R. Subedi, R. Suleiman, V. Sulkovsky,
B. Wojtsekhowski (contact and spokesperson), X. Zheng.

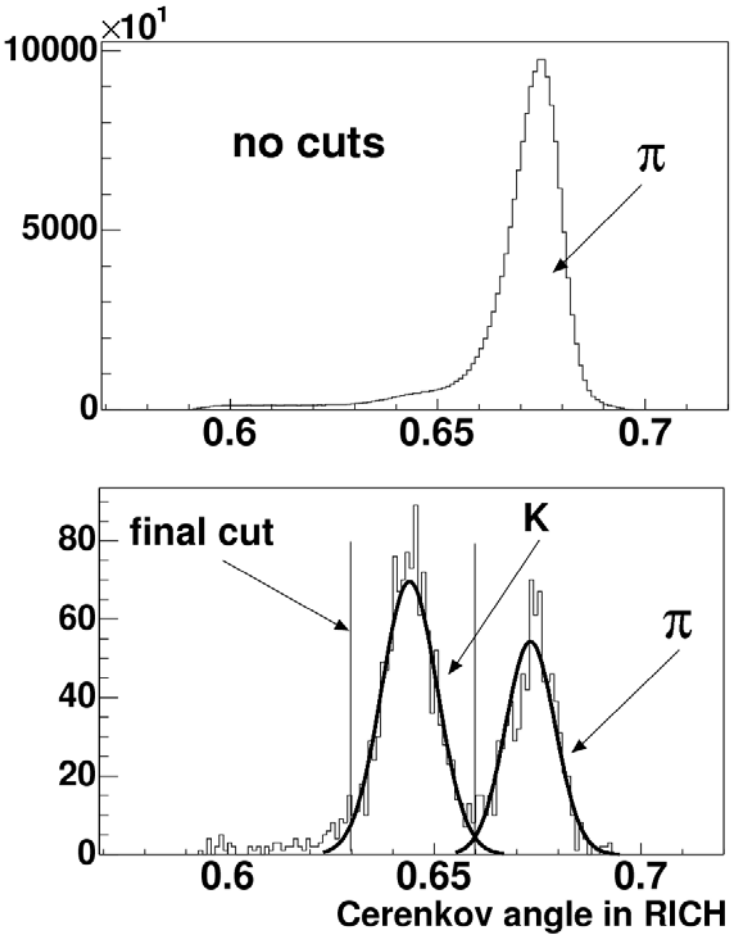
and the Hall A Collaboration

PID System

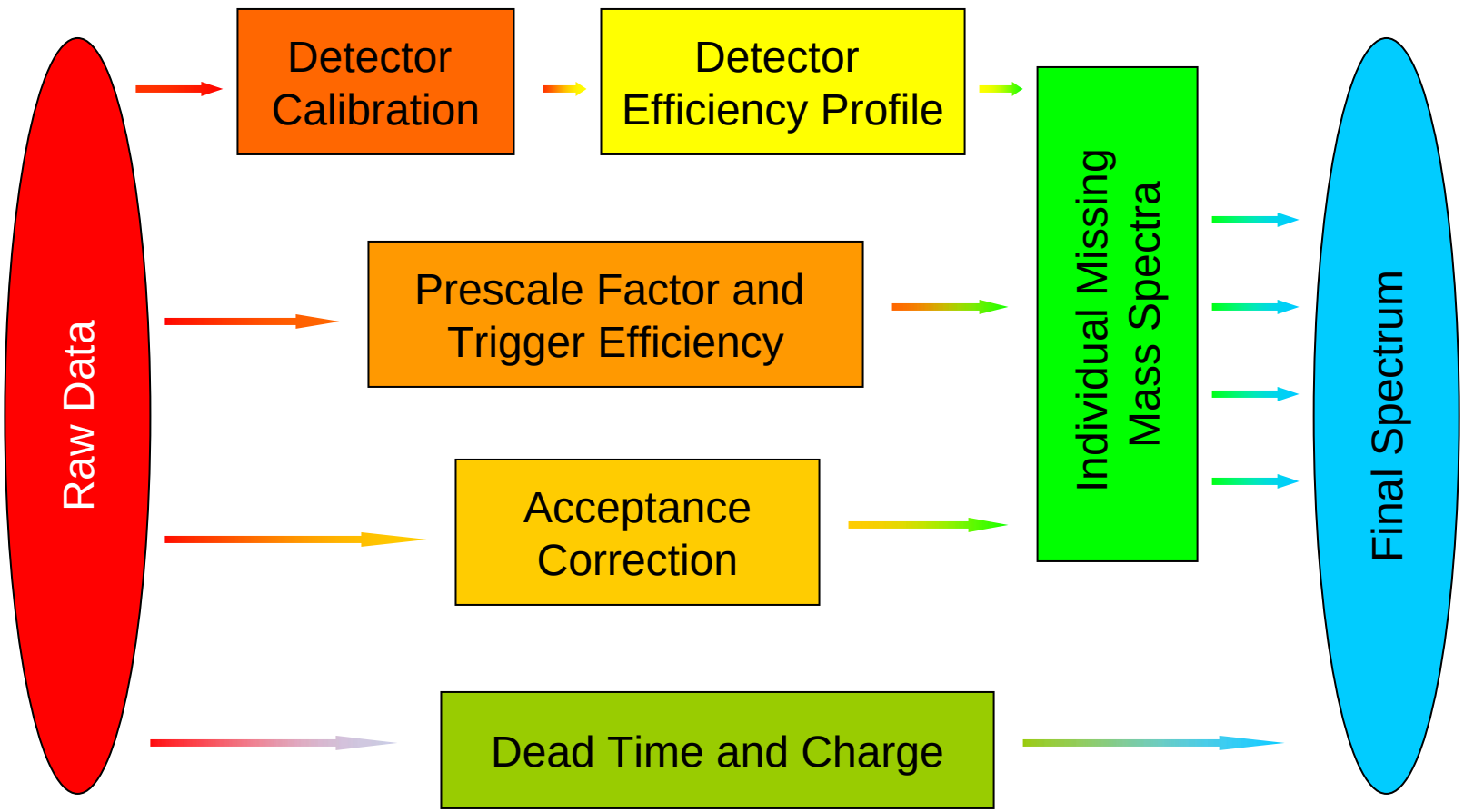
- Left Arm:
  - Aerogel 1/2 (n = 1.015/1.055)
  - RICH (n = 1.30)
  - Pion Rejecter
- Right Arm:
  - Gas Cherenkov
- Timing and Spatial Coincidence

π Rejection ≈ 3·10⁴

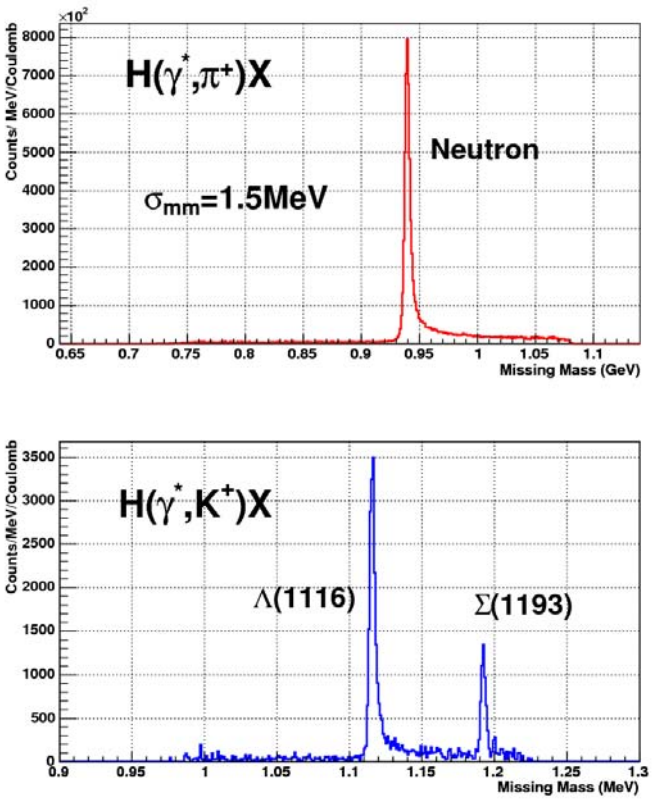
Final K/π ratio > 20



Analysis Step by Step



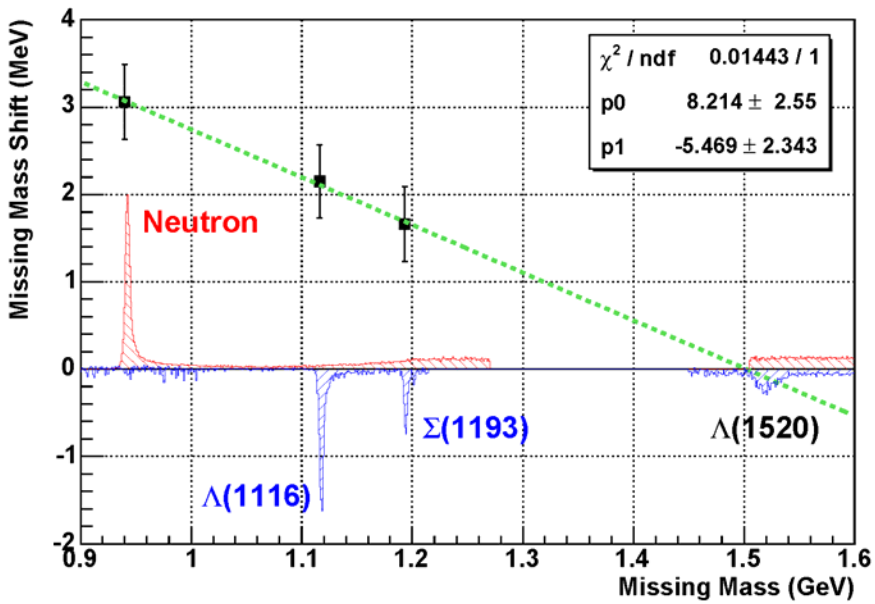
High Resolution and Mass Calibration



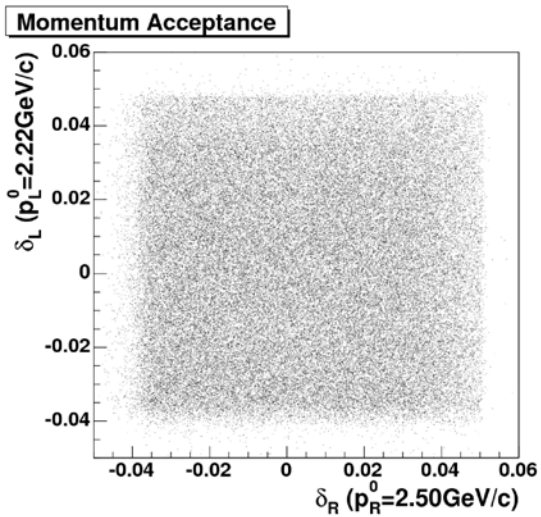
Missing Mass Resolution

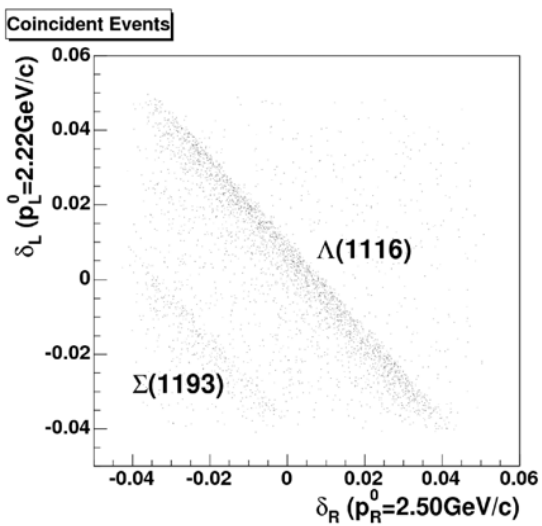
$\sigma_{mm} = 1.5\ MeV$

Mass Uncertainty < 3 *MeV*



Acceptance Correction at 6°

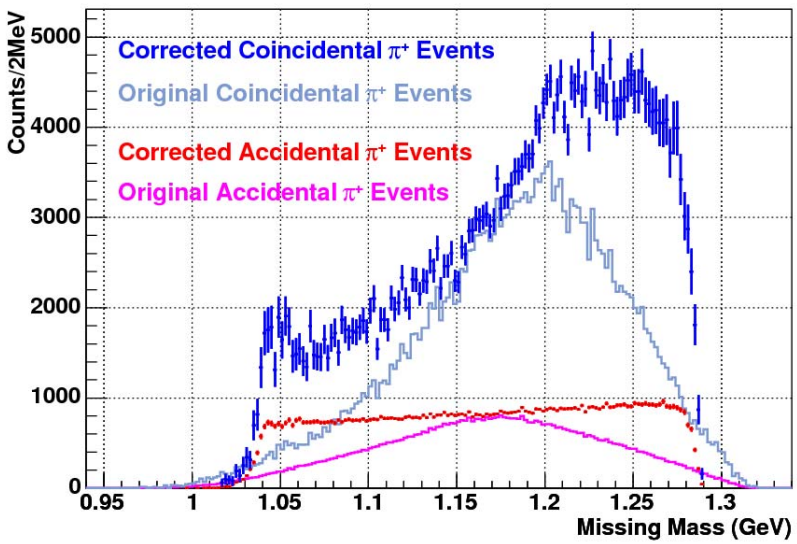




$$e + p \rightarrow e' + \pi^{\pm}(K^{\pm}) + X$$

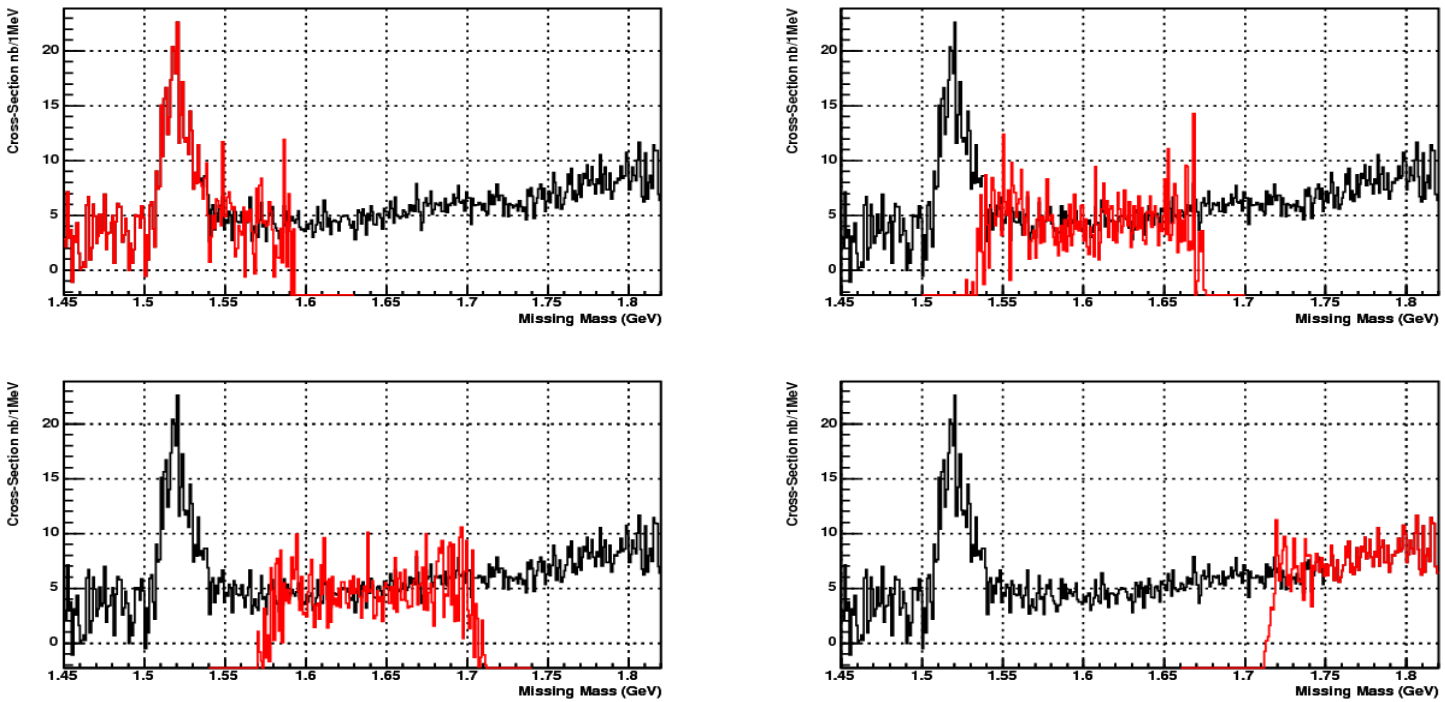
$$M_X \approx C - P_{e'} - P_{\pi(K)}$$

Missing Mass Acceptance is proportional to the Length in 2D momentum acceptance plot



Combine Kinematics Settings

Effective charges are taken account in Missing Mass Combination, red curves show different settings

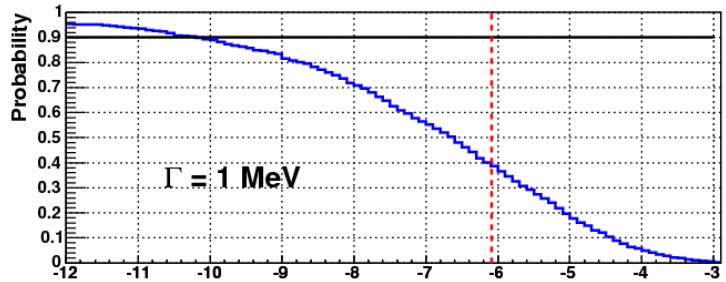


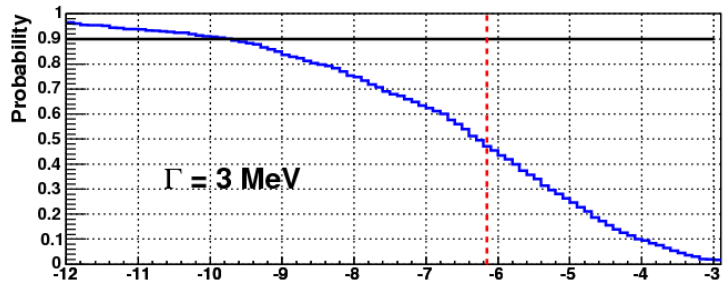
The Combination is very smooth!

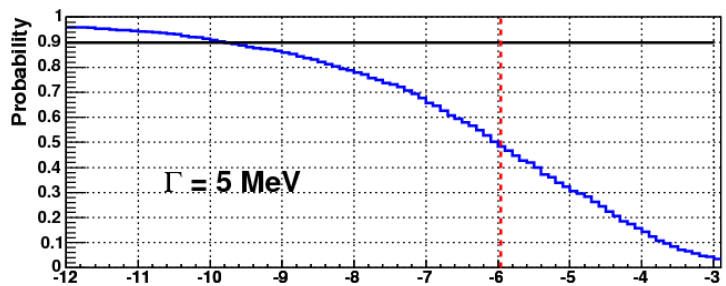
Background MC

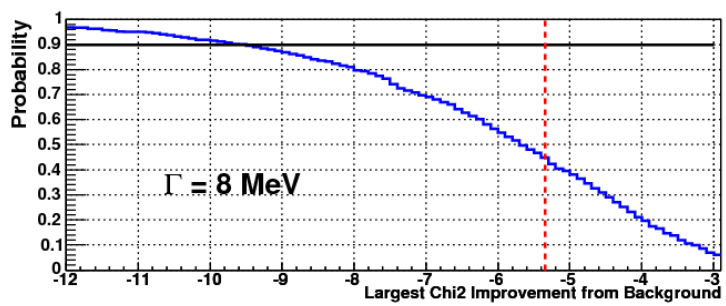
- The probability is only less than **50%** that the peaks with greatest chi-square improvement of our experiment are real!

- No observation of narrow peaks and go for upper limits



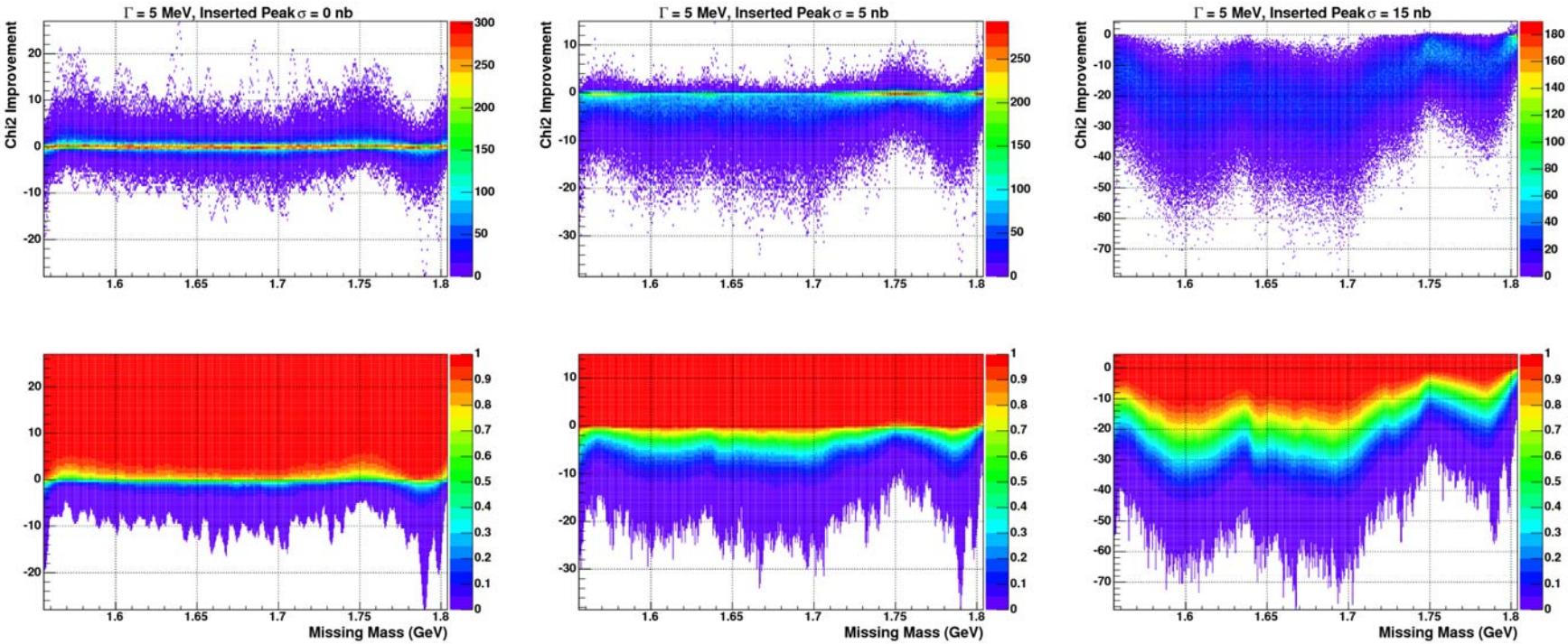






MC with Resonances Inserted

$\sigma = 0nb$ $\sigma = 5nb$ $\sigma = 15nb$



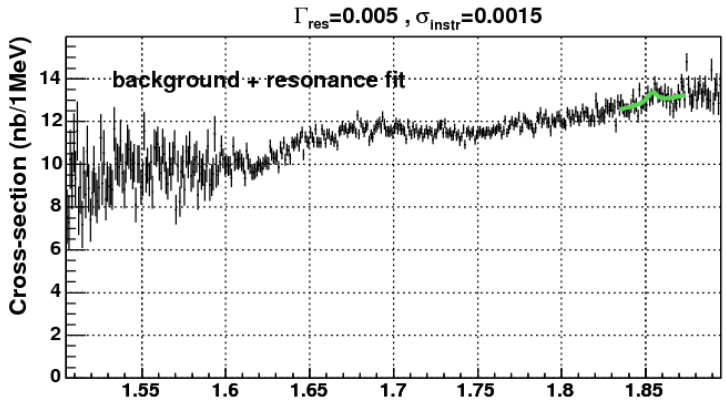
- To find the contours of X_{σ}^{90} satisfying:

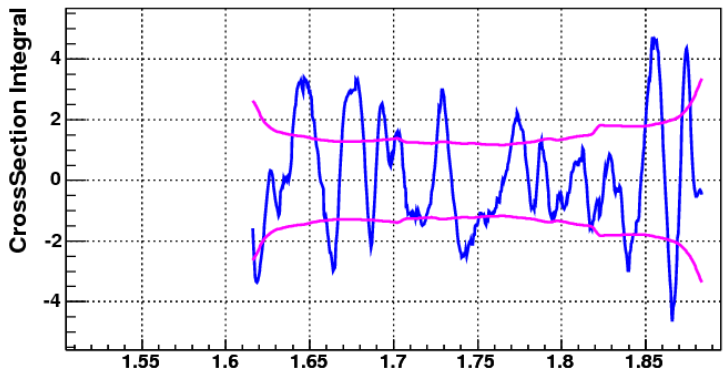
$$P_{\sigma}(\Delta\chi^2 \le X_{\sigma}^{90}) = 90\%$$

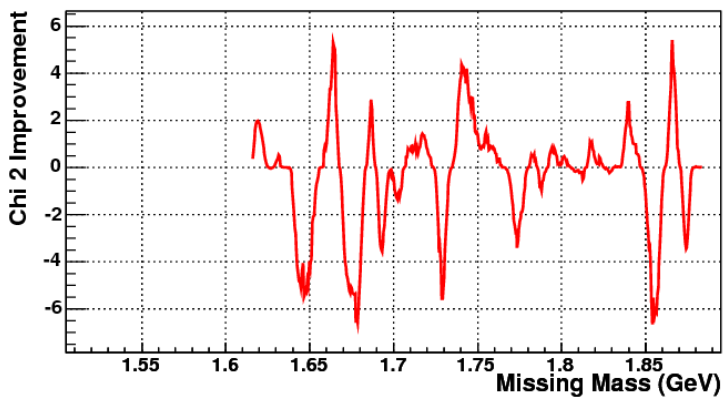
N°_{10} Search

$$H(e,e'K^{+})N^{o}_{10}$$

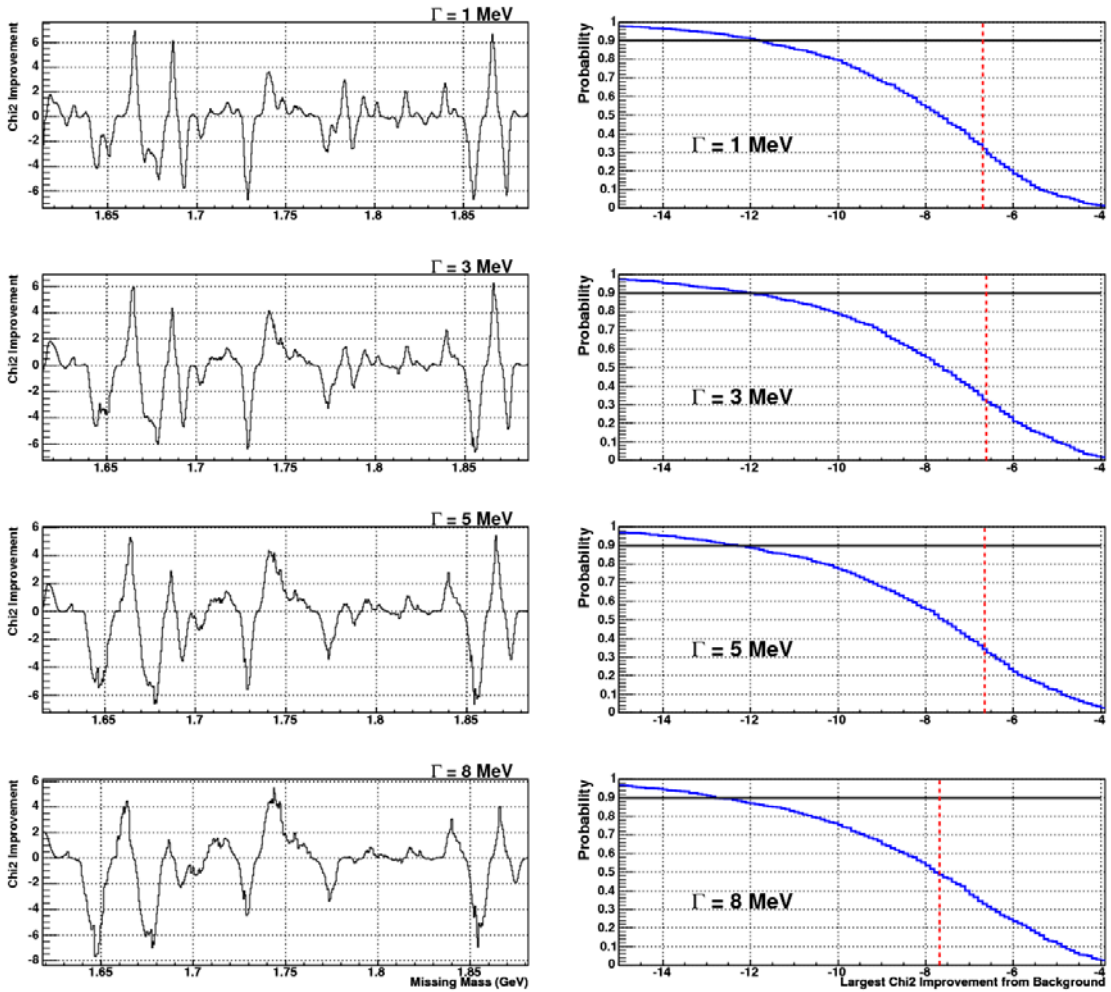
1610 ~ 1890 *MeV/c²*







$N^{\circ}_{\overline{10}}$ Fit and MC



Probability of

Real Peak:

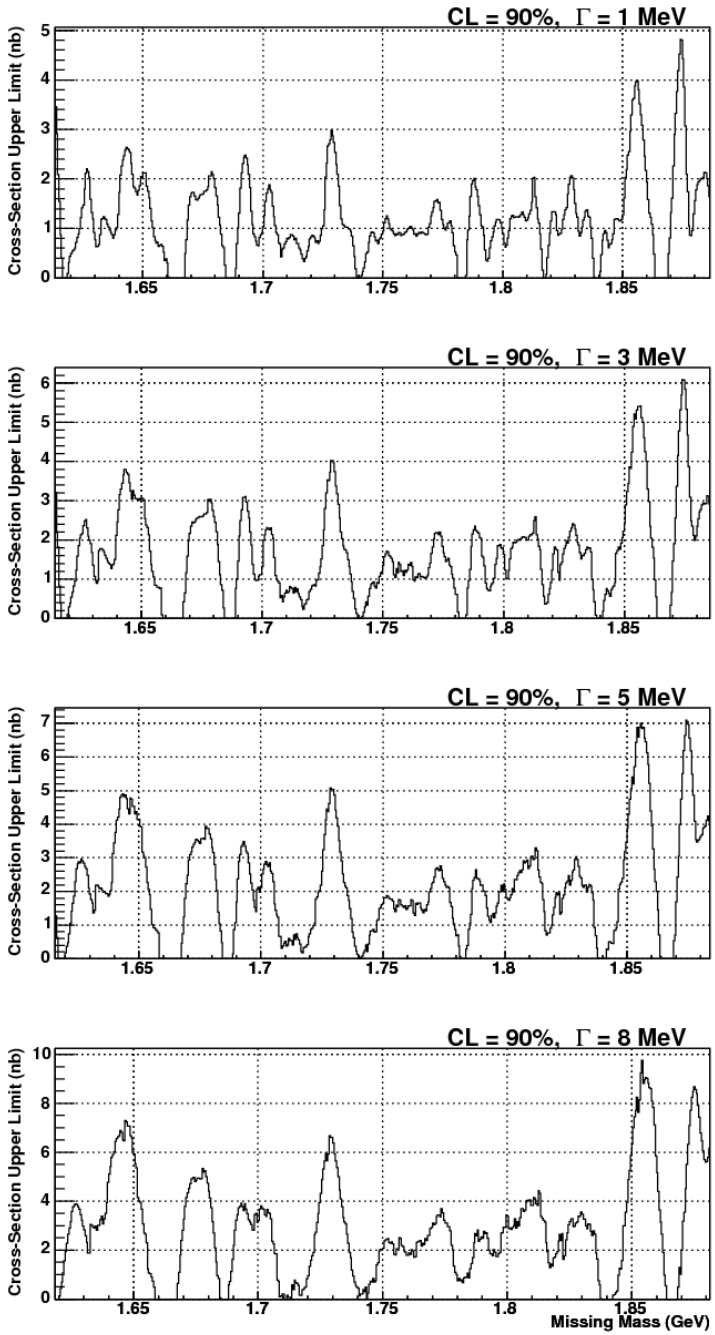
< 50 %

N°_{10} Upper Limits

- Most Significant Peak is found at **1.65**, **1.68**, **1.73** and **1.855** GeV/c^2

- 90% CL upper limits at those positions range:

4 nb/sr ~ **9** nb/sr



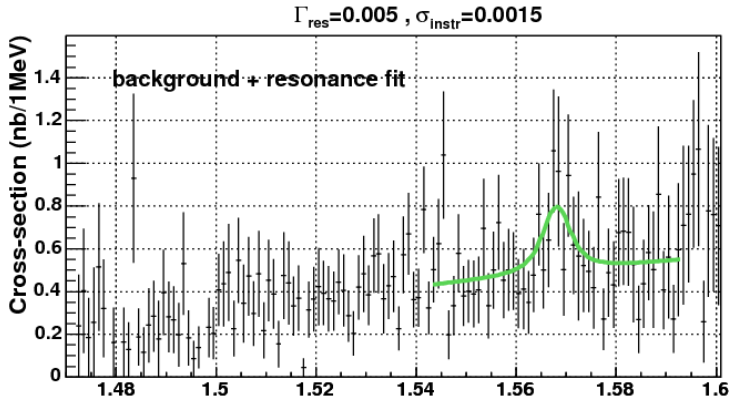
Θ^{++} Search

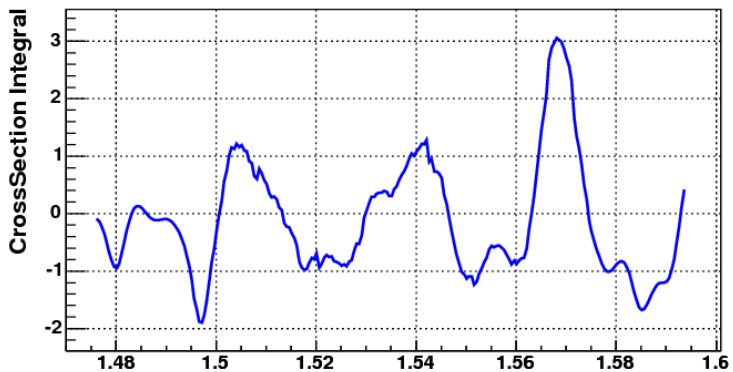
$$H(e,e'K^-)\Theta^{++}$$

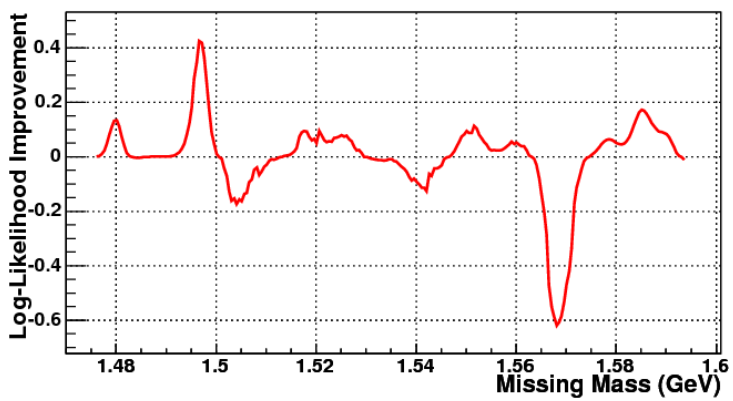
1470 ~ 1600 *MeV/c²*

Low statistics requires us to change from

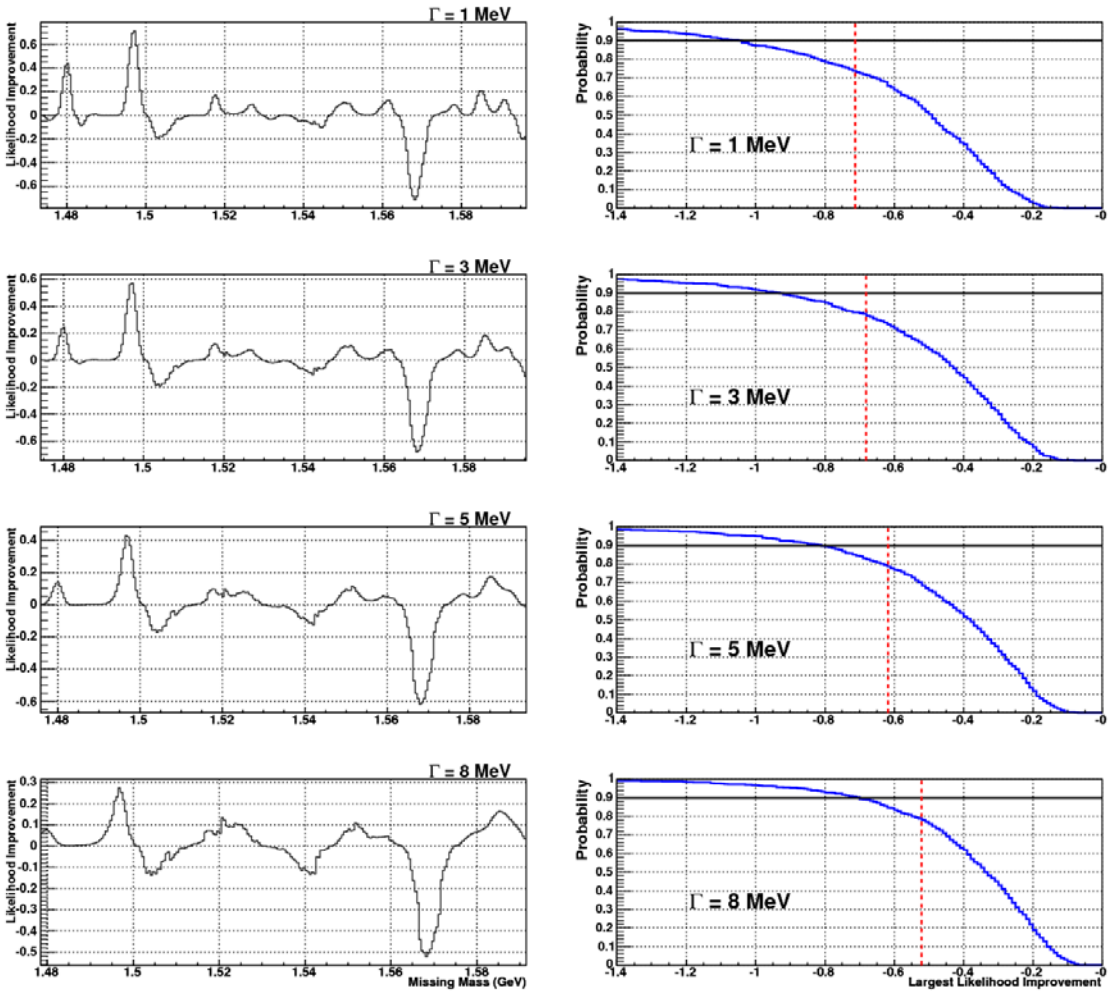
χ^2 to Log-Likelihood







Θ^{++} Fit and MC



Probability of

Real Peak:

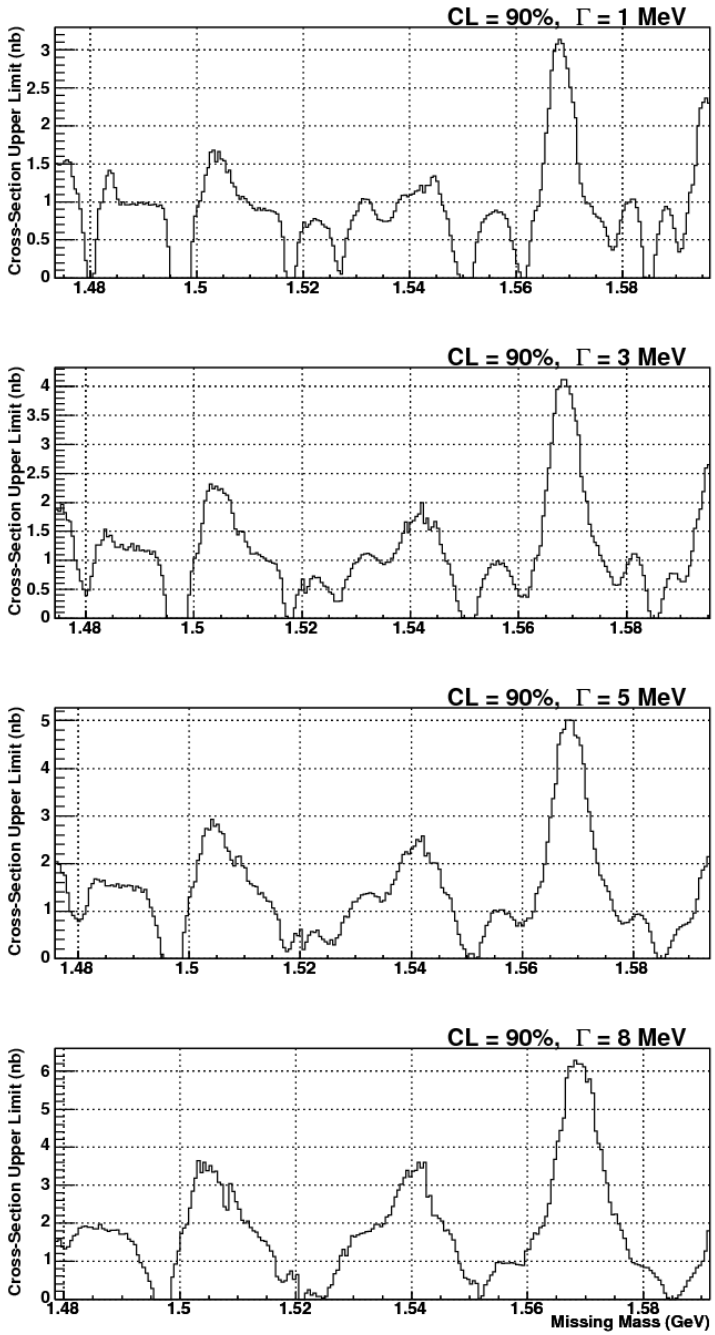
< 80 %

Θ^{++} Upper Limits

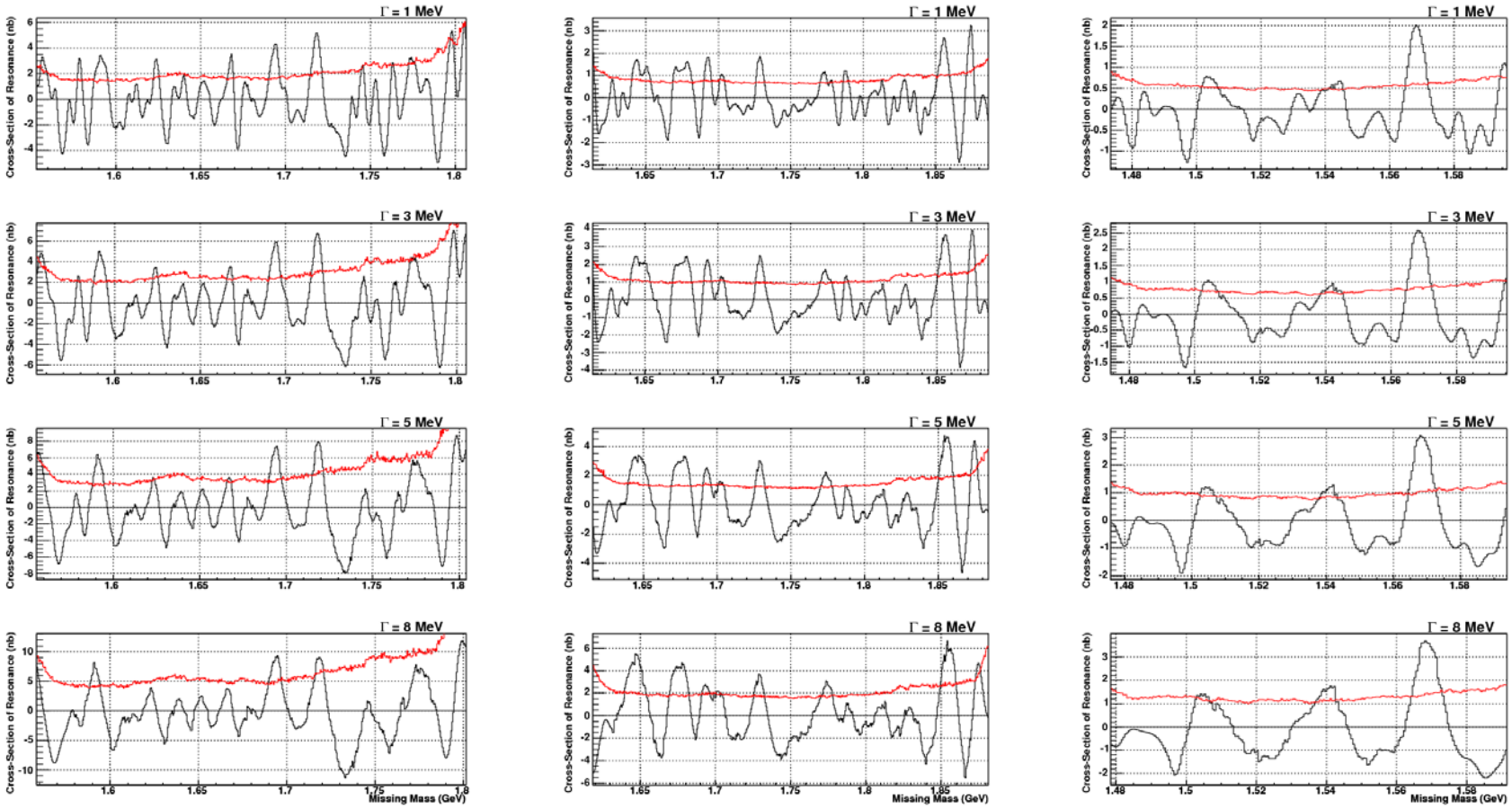
- Most Significant Peak is found at **1.57** GeV/c^2

- 90% CL upper limits at those positions range:

3 nb/sr ~ **6** nb/sr

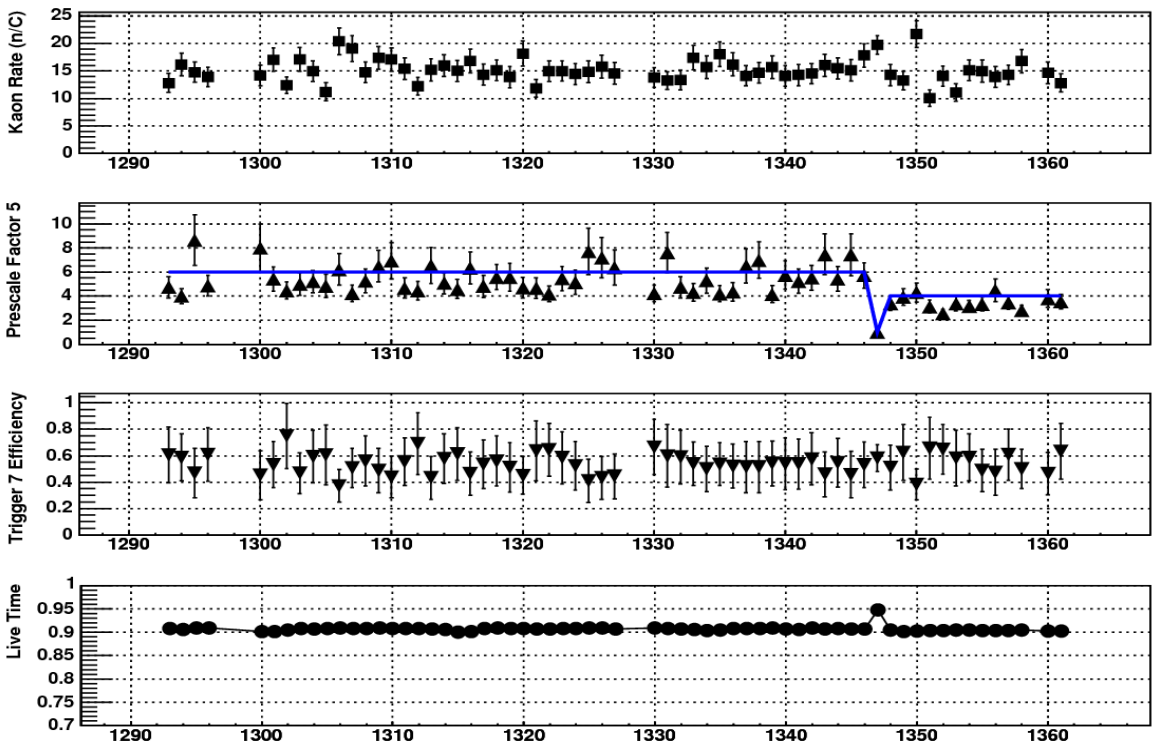


Fitted Cross-Sections



Data Quality

- The Uniformity of Kaon rate run by run shows the good quality of our data



Kaon Rate

Prescale Factor of Trigger 5

Trigger 7 Efficiency

Live Time